STUDY BY THE STAFF OF THE U. S. GENERAL ACCOUNTING OFFICE

Space Telescope Project

National Aeronautics and Space Administration

The Space Telescope will be the largest, most complex space observatory ever developed. NASA expects it to signigicantly extend man's knowledge of the universe and perhaps answer the age old question: 'Are we alone in the universe?'

NASA plans to request funds in its fiscal year 1977 budget to initiate hardware development. This study provides the Congress with information on the project's need and expected benefits; current cost, schedule, and technical status; technical development uncertainties; and progress measurement system.

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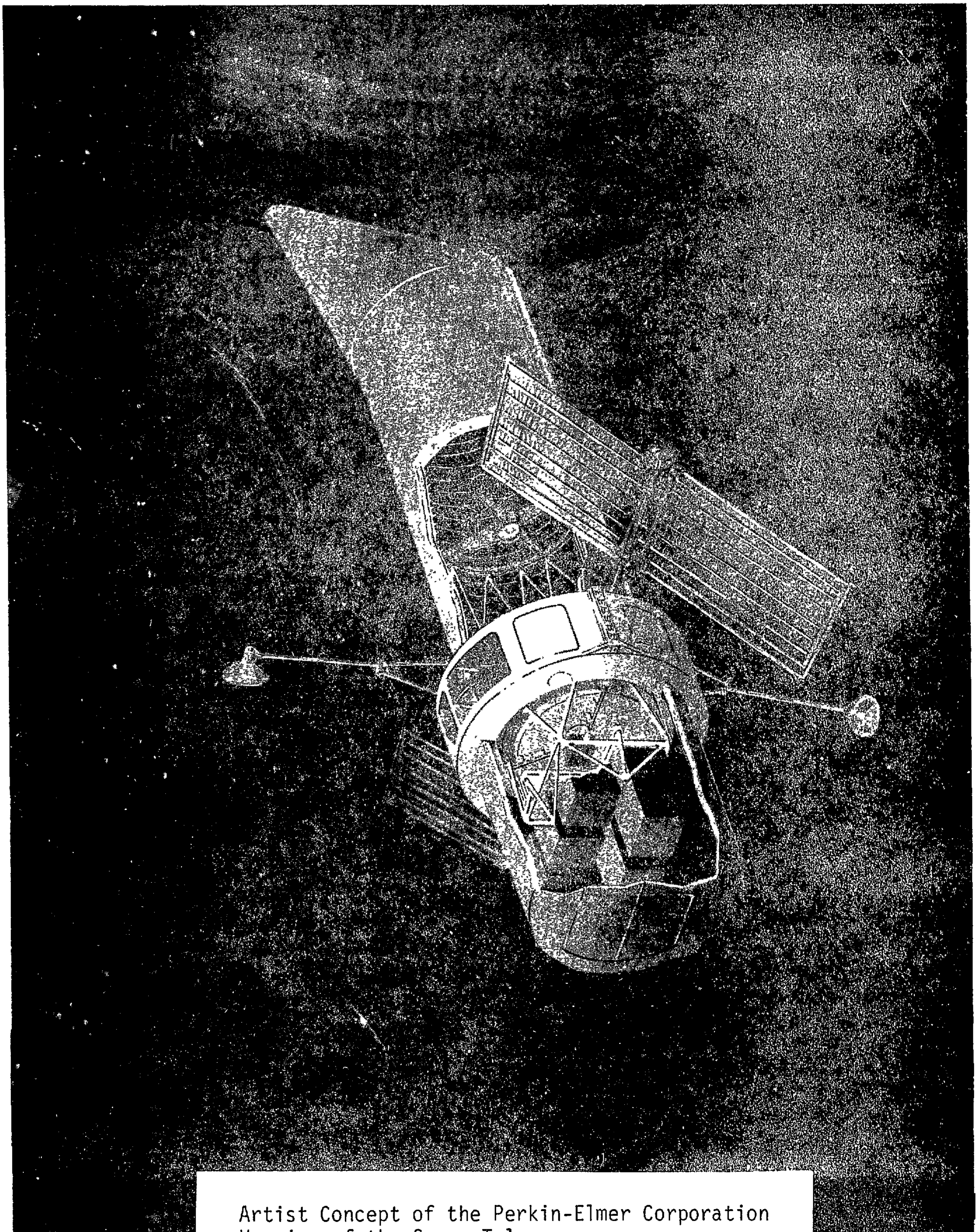
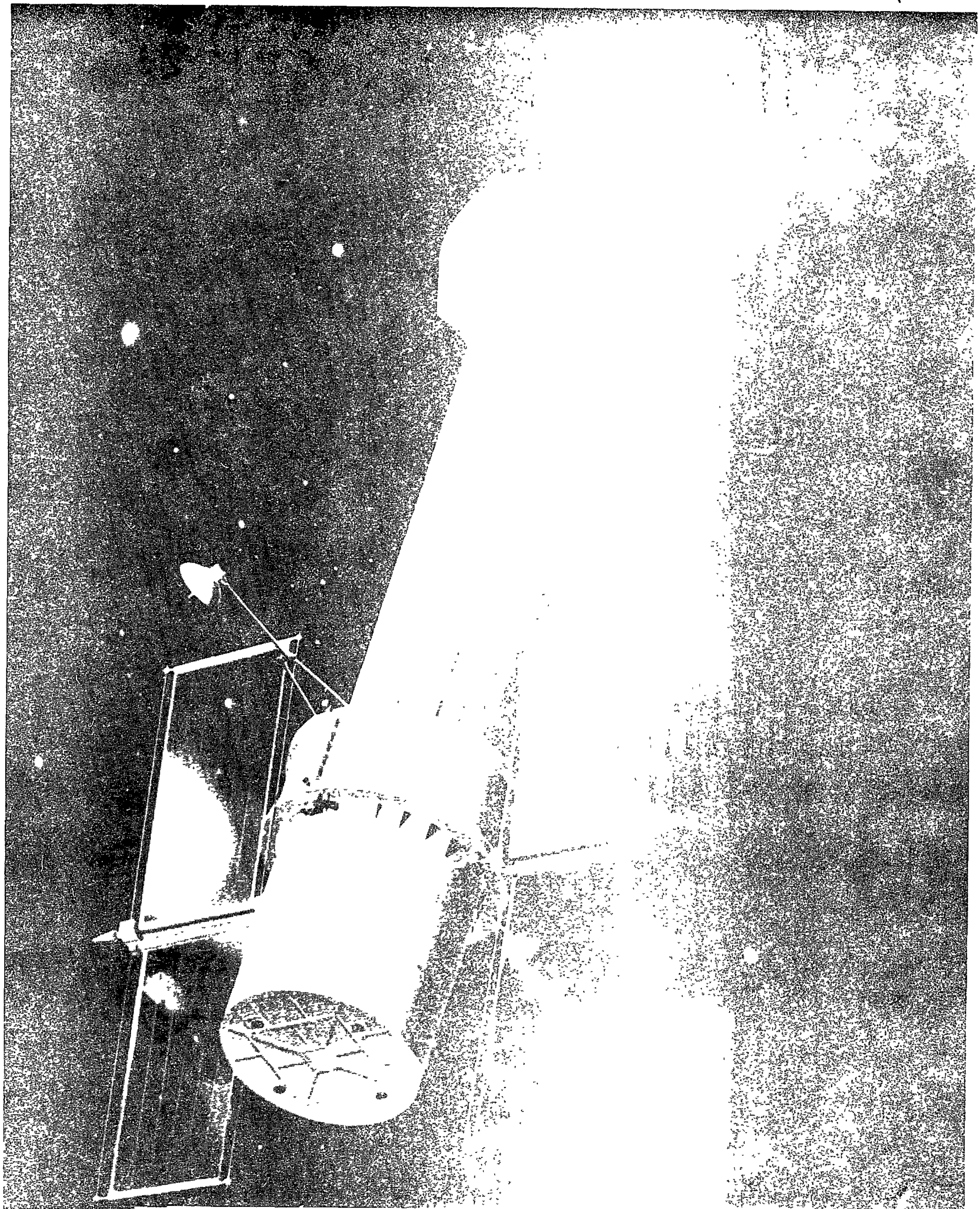


Artist Concept of the Perkin-Elmer Corporation
Version of the Space Telescope



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UNITED STATES GENERAL ACCOUNTING OFFICE
WASHINGTON, D.C. 20548

PROCUREMENT AND SYSTEMS
ACQUISITION DIVISION

The General Accounting Office has performed a study of the Space Telescope project that is currently in the definition phase of the National Aeronautics and Space Administration's (NASA) acquisition cycle. The study was primarily concerned with the project's cost, schedule, and performance goals including technical development uncertainties.

This staff study is our first review of the Space Telescope and its purpose is to provide information that will aid the Congress in evaluating NASA's request for fiscal year 1977 funds. A draft of this study was reviewed by agency officials associated with the management of this project and their comments are incorporated as appropriate.

Copies of this study are being sent to the Chairman of the Subcommittee on HUD and Independent Agencies, Senate Committee on Appropriations at whose request we performed this review. Copies are also being sent to the Chairmen of the Senate Committees on Appropriations, Aeronautical and Space Science and Government Operations; and the House Committees on Appropriations, Science and Technology and Government Operations; members of Congress from the States of Alabama and Maryland; and other members of Congress who have requested copies of staff studies. We are also sending copies to the Administrator, National Aeronautics and Space Administration.

R. W. Gutmann
Director

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ABBREVIATIONS

ESA	European Space Agency
GSFC	Goddard Space Flight Center
JSC	Johnson Space Center
KSC	Kennedy Space Center
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
OSS	Office of Space Science
OTDA	Office of Tracking and Data Acquisition
ST	Space Telescope
UK	United Kingdom

SPACE TELESCOPE PROJECT

INTRODUCTION

The Space Telescope (ST) project, formerly called the Large Space Telescope, will be the largest, most complex space observatory ever developed by the National Aeronautics and Space Administration (NASA).

NASA established the following scientific objectives for the project: develop a better understanding of (1) the origin and evolution of the universe, (2) the stars, galaxies, and the nature and behavior of materials and fields between them, and (3) the physical aspects of the universe.

SUMMARY

The scientific community currently supports the ST project and believes it will greatly assist in resolving unanswered questions in astronomy. Some of this support may be lost if the cost of the ST causes reductions in funds needed for other projects deemed necessary for a balanced astronomy program. (See p. 13)

NASA is presently defining the project and plans to request congressional approval in its fiscal year 1977 budget to begin hardware development. NASA's most recent revised planning estimate shows a cost range of $370 million to $445 million to acquire the ST. A firm life-cycle cost estimate has not been prepared. (See p. 20)

Marshall Space Flight Center's preliminary assessment data examined by GAO shows that about $318 million in fiscal year 1975 dollars could be required for tracking and data acquisition and operation costs throughout the expected 15 year life of the project. These estimates do not

include costs for NASA personnel or Space Shuttle transportation. Estimates for these costs were not readily available. (See p. 20)

Although no formal commitments have been made, NASA estimates an $18 million reduction in cost from work to be provided by international participants. (See pp. 8 and 19)

Current schedules show a planned launch date of April 1983 which represents a 4-month slippage in the initial launch schedule. (See p. 22)

In response to a congressional directive to explore lower cost objectives, NASA recently reduced the ST's aperture size. This will reduce its operational effectiveness. Some effectiveness may be lost initially because of several critical technical uncertainties. However, NASA is placing special emphasis on these matters in order to resolve them on a timely basis and feels it will be successful. This could impact on cost. (See pp. 7, 23 and 27)

NASA uses a less formal system for assessing cost, schedule, and technical progress during its definition work than the formal progress measurement system it plans to implement if the ST is approved for development. (See pp. 35 and 36)

Program plans currently provide for establishing a unique scientific activity, referred to as the ST Science Institute, to manage certain operational aspects of the ST. The Institute may operate under contract with NASA. (See p. 9)

KEY ISSUES FOR CONSIDERATION BY THE CONGRESS

In evaluating the request for funds for fiscal year 1977, the Congress should consider the following:

- --The possible loss of support from the scientific community if NASA's funding requirements for the ST would preclude it from carrying out a balanced space astronomy program.
- --The need for a firm life-cycle cost estimate which includes all development and operational costs associated with the project.
- --The performance degradations which could result unless present technical uncertainties are resolved and NASA's reasons for its confidences that the resolutions can be made within presently established cost constraints.
- --NASA's management and funding responsibilities with respect to post launch operations of the ST Science Institute.
- --Requiring NASA to submit periodic program status reports on the ST. This will allow Congress to track ST's progress from inception throughout its life.

QUESTIONS

The following questions relate to matters identified but not fully developed during our review. The Congress may want to pursue these matters further with NASA during the authorization and appropriations deliberations.

1. Will NASA's funding requirements for the ST divert funds from other projects deemed necessary to maintain a balanced space astronomy program?
2. What are the results of the recent Space Science Board's study on priorities in space research? Does this organization still consider the ST project to be the highest priority program in astronomy?

3. What is the current life-cycle-cost estimate for the ST project? Does it include all cost associated with the project?

4. What specific research data can not be obtained with the 2.4-meter ST that could have been obtained with the 3.0-meter instrument?

5. What is the current status of the work on (1) development of the primary mirror and detectors for the scientific instruments, (2) fine pointing and stabilization controls, (3) definition of contamination controls, and (4) development of thermal controls? Can these areas be satisfactorily resolved without performance degradations?

6. Since certain factors, such as the ST's physical size, prevent full operational testing prior to launch, how much technical risk is NASA taking? Explain the limited test program presently planned.

7. What are the specific duties and responsibilities of the ST Science Institute? How much control over the operations will NASA have? What are the estimated annual funding requirements for the Institute?

AGENCY REVIEW

A draft of this staff study was reviewed by NASA officials associated with the management of this project and comments are incorporated as appropriate. As far as we know, there are no residual differences in fact.

CHAPTER 1

INTRODUCTION

This staff study contains the results of our first review of the Space Telescope (ST) project which will be the largest, most complex space observatory ever developed by the National Aeronautics and Space Administration (NASA).

The study contains information on the project's (1) stated need and expected benefits, (2) current cost, schedule, and technical status, (3) technical development uncertainties, and (4) progress measurement system.

OBJECTIVES

The primary objective of the ST project is to develop and operate a large, high resolution space telescope system which will be useful to the international scientific community and significantly extend man's knowledge of the universe.

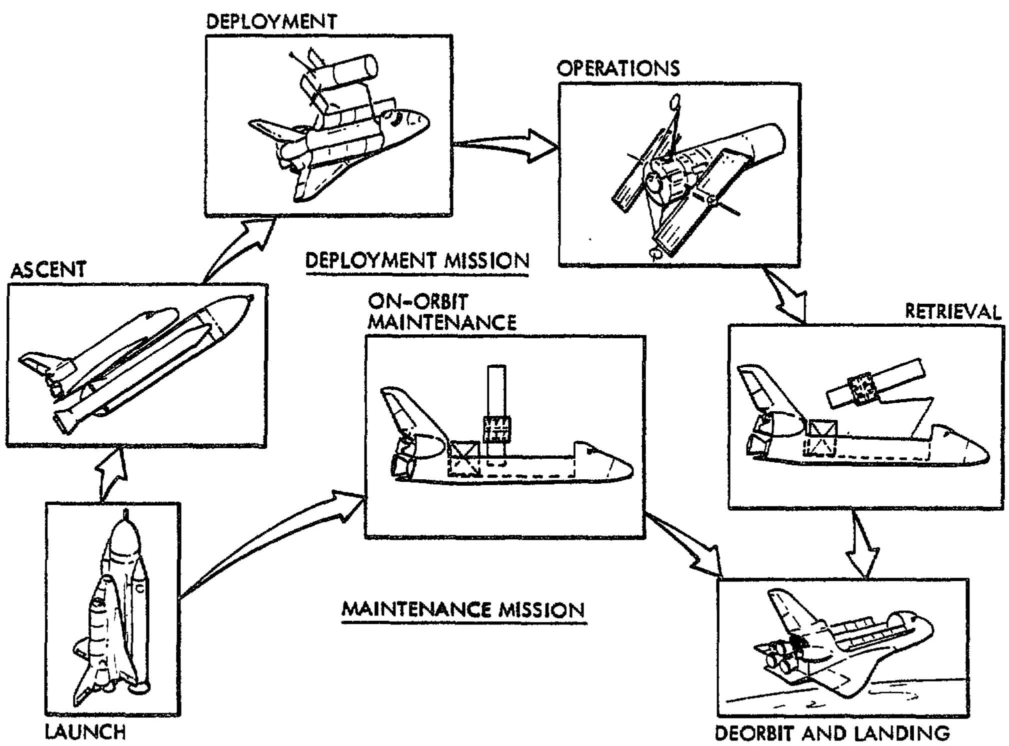
NASA established the following scientific objectives for the project: develop a better understanding of (1) the origin and evolution of the universe, (2) the stars, galaxies, and the nature and behavior of materials and fields between them, and (3) the physical aspects of the universe.

DESCRIPTION

The ST project includes the design, development, production, launch, and orbital verification of an unmanned astronomical observatory consisting of an optical telescope assembly, scientific instruments, support systems module, and all unique equipment and procedures needed to test, handle, launch, and support on-orbit operations.

The ST is to be launched by the Space Shuttle and inserted into a circular orbit at an altitude of about 270 nautical miles with an inclination of 28.8 degrees. A mission operations center will send commands to the spacecraft and monitor the status of its systems, determine failures, and identify degraded systems.

The Space Shuttle is to rendezvous with the ST when necessary for limited maintenance and servicing. When major maintenance is necessary, the Shuttle will bring the ST to Earth for refurbishment to extend its life and to upgrade its scientific capability. The following illustration shows the various stages of an ST mission.



Stages of an ST Mission

HISTORY

In late 1971 NASA and its contractors initiated detailed feasibility studies of the ST for the purpose of identifying spacecraft configurations, investigating maintenance modes and associated costs, establishing reliability and lifetime goals, and evaluating mission and hardware feasibility. The studies were completed in December 1972, and NASA concluded that development and operation of an optical space telescope with a 3.0-meter aperture was feasible.

In April 1973 the NASA Administrator approved initiation of the definition phase which includes detailed studies, comparative analyses, and preliminary design for the purpose of selecting a single project approach. In August 1973 NASA awarded contracts to two competing contractors for parallel definition of the optical telescope assembly and scientific instruments. In December 1974 NASA awarded contracts to three competing contractors to complete definition of the support systems module. Although contractors are doing most of the definition work, NASA employees accomplished part of the effort in-house.

During fiscal year 1975, the Congress directed NASA to investigate means to reduce cost and to obtain international participation in the project. Pursuant to the congressional guidance, NASA directed its definition contractors to evaluate instruments with 1.8-meter, 2.4-meter and 3.0-meter apertures for the purpose of selecting the most cost effective approach. NASA also contacted potential international participants.

In May 1975 the NASA Administrator selected the 2.4-meter system for final definition because (1) its projected weight was well within Space Shuttle payload requirements, (2) required technology was considered to be within the current state-of-the-art, (3) estimated costs were substantially less than the 3.0-meter system, and (4) the 2.4-meter system was considered to be capable of achieving the established minimum scientific objectives.

NASA representatives visited the United Kingdom (UK) and the European Space Agency (ESA) to determine their interest in participating in the project. Both UK and ESA expressed an interest to participate, but as of November 1975 they have not made formal commitments. NASA's current plans contemplate ESA developing and providing one of the scientific instruments and portions of the solar power system.

MANAGEMENT

NASA's Office of Space Science (OSS) is responsible for overall management of the ST project which includes establishing policy and technical requirements, approving plans, determining goals and objectives, and allocating funds. Marshall Space Flight Center (MSFC), NASA's lead center for the project, is responsible for project implementation to meet cost, schedule, and performance goals.

Goddard Space Flight Center (GSFC) is responsible for developing the ST's scientific instruments and managing mission operations and data reduction. Johnson Space Center (JSC) and Kennedy Space Center (KSC) are responsible for Space Shuttle and ST interface requirements and launch operations, respectively. NASA's Office

8 of Tracking and Data Acquisition (OTDA) will be responsible for providing tracking and data acquisition support. DLG 01055

In addition to these activities, NASA's present plans provide for establishing a unique science operations element referred to

9 as the ST Science Institute. The Institute probably will be operated under contract with NASA by a corporation formed from a consortium of universities and will include a staff of scientists. This group is expected to provide services to a wide spectrum of the scientific community, including Government scientists. The responsibilities of the Institute will include control of viewing requirements, science mission planning, science data processing, guest observer selection, and science data management. DLG 01056

SCOPE OF REVIEW

Information contained in this study was obtained by reviewing project plans, reports, correspondence, and other documents prepared by NASA, its contractors, and other organizations. We also

10 discussed various aspects of the project with NASA and Space Science Board officials. DLG 01057

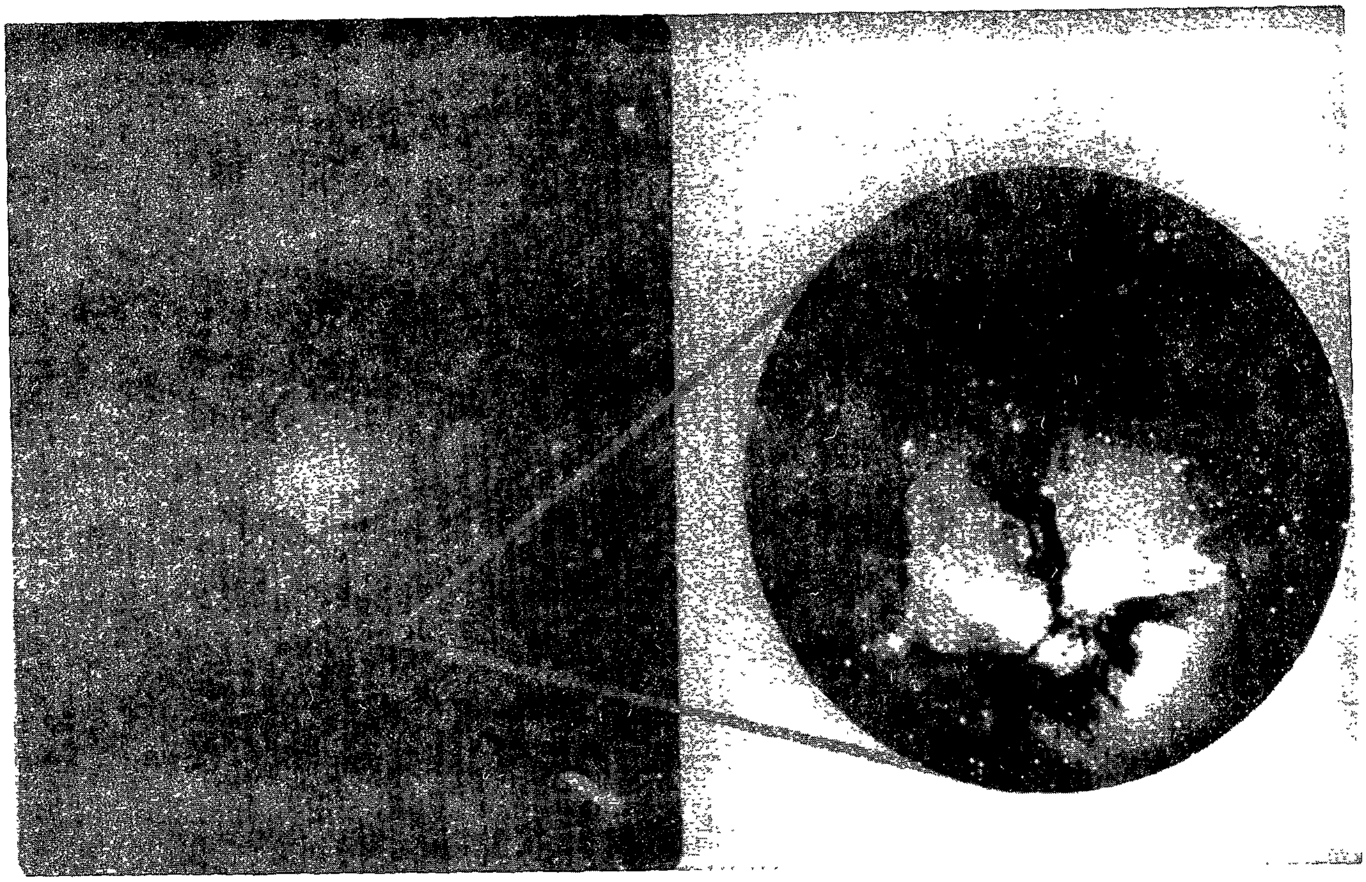
CHAPTER 2

PROJECT JUSTIFICATION

Over the past several decades, the scientific community has made many studies and evaluations of the need for a powerful space telescope and the advancements that could be made in astronomy with the instrument. These studies have strongly supported the space telescope concept and concluded that major questions in astronomy could be resolved.

LIMITATIONS OF GROUND-BASED TELESCOPES

As early as 1923, a scientist pointed out that an astronomical telescope in orbit far above the atmosphere would have tremendous advantages over ground-based instruments. Subsequent studies compared the capabilities of our largest ground-based telescope--the 200-inch Hale telescope at Palomar Mountain, California--with those projected for the ST and concluded that the ST would have significant advantages. The Hale telescope, for example, can recognize individual galaxies about 2 billion light years away, but like all ground-based devices, it has limited capability because of the fluctuation, distortion, and absorption effects caused by the Earth's atmosphere. The following compares the imaging capability of the Hale telescope with that expected from the ST.



Ground-based Capability Versus
Expected ST Performance

The atmosphere blocks out most of the shortwave radiation emitted by the Sun and stars; therefore, observations made by ground-based telescopes are restricted to a small fraction of the electromagnetic spectrum. In past years, therefore, astronomers could only study the physical nature of objects emitting thermal energy of a few thousand degrees in the form of visible light. Very hot or very cold objects or those that gave off exotic, nonthermal radiation were beyond understanding.

Space telescopes have a number of important advantages over ground based telescopes. They can, for example, intercept radiation that cannot penetrate the atmosphere. Ground-based telescopes must also look through columns of turbulent air which severely degrades images they produce. A 120-inch (about 3.0-meters) telescope above the Earth's atmosphere would have 10 times the resolving power of the 200-inch (about 5.0-meters) Hale telescope operating under the best atmospheric conditions. Because of the very small image sizes that are possible with space telescopes, one with a 120-inch aperture should be able to detect starlight about 100 times fainter than the faintest detectable from Earth. Data on such faint objects are critical to assist in settling major cosmology[1] questions such as whether the universe is infinite.

Another problem caused by the atmosphere is that it deflects the light that passes through, and the deflections limit the sharpness of most astronomical photographs. An optical telescope in space, however, can effectively focus photons (electromagnetic radiation) with various wavelengths; therefore, the entire spectrum can be measured with a single instrument. The capability to make measurements at wavelengths previously inaccessible and to obtain much sharper images at visible wavelengths is expected to open new fields of space research.

Astronomers therefore believe that the ST will assist in resolving major questions in astronomy which cannot be answered

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[1]Cosmology is the branch of science dealing with the study of the universe as a whole and its content, structure, scale, and evolution.

with data obtained from ground-based telescopes. Astronomers believe that use of the ST can provide valuable information concerning the scale and curvature of the universe, galaxies and quasars, density and composition of matter in the universe, structure of asteroids and cometary nuclei, planetary atmospheric and surface structure, composition of stars in neighboring galaxies, and physical nature of pulsars.

Quasars are starlike celestial objects that emit immense quantities of light or powerful radio waves or both. These objects appear to be extremely distant from the Earth. In addition to the nine major planets, our galaxy contains minor planets called asteroids. Usually located in the gap between Mars and Jupiter, asteroids appear as stars when viewed with a telescope. Cometary nuclei are the nuclei of comets and are composed of various ices, such as water, ammonia, methane, and carbon dioxide. A nucleus also contains small portions of metallic or stoney lumps. Pulsars are defined as any of several small heavenly objects in the Milky Way that emit radio pulses at regular intervals.

SUPPORT BY THE SCIENTIFIC COMMUNITY

Prior to 1956 there was little discussion of anything as ambitious as the ST, but since that time the situation changed dramatically following the successful launching of satellites in 1957. In late 1961, about three years after it was organized, NASA requested the Space Science Board, National Academy of Sciences, to form two study groups for the purpose of making recommendations on future space research.

When the first study group met in 1962, the Orbiting Solar Observatory had been launched and the Orbiting Astronomical Observatory program was well into the hardware development phase. The study group considered programs which were expected to be accomplished well into the future and concluded that a larger telescope of 100 inches or more would represent an enormous advancement for astronomy. For this reason, the group concluded that the scientific justification for the instrument should receive careful and comprehensive consideration by the astronomical and related scientific communities. The second study group met in 1965, and it also concluded that a space telescope of a very large diameter would be uniquely important to the solution of central astronomical problems.

Subsequent to these evaluations, the Space Science Board appointed an Ad Hoc Committee to make further studies of the ST concept, and in 1969 this group published a report on specific research programs which could be carried out with the instrument. The Ad Hoc Committee concluded that the ST would make a dominant contribution to man's knowledge of cosmology and that it also would give important and decisive information in many other fields of astronomy. The group pointed out, however, that an effective space astronomy program could not be carried out by the ST alone and that smaller telescopes, including ground-based instruments, would still be required.

Increased emphasis was given the ST by scientists in general and from the astronomical community in particular. The project was strongly endorsed by a variety of scientific committees including the NASA Astronomy Mission Board, Space Science Board and Astronomy Survey Committee of the National Academy of Sciences, and the President's Science Advisory Committee.

The Astronomy Survey Committee concluded in 1972, for example, that the ST had extraordinary potential for a wide variety of astronomical uses and that it should be a major goal in any well planned program of ground and space-based observations. In addition, the National Academy of Sciences in its 1974 report on opportunities and choices in space sciences considered the ST to be the highest priority program in astronomy. Although the National Academy of Sciences assigned the ST highest priority of all space astronomy missions, it cautioned that the project's cost should not jeopardize the achievement of a balanced program that exploited scientific opportunities in all areas of space astronomy.

In FY1976, NASA's appropriation includes about $120 million for office of Space Science (OSS) astronomy programs. This does not include the cost of launch vehicles. We were advised by an official in OSS that for all intents and purposes, this figure represents NASA funded astronomy effort.

Although the ST still has the support of the scientific community, an official of the Space Science Board told us that the cost of the ST project was becoming an increasing concern throughout the scientific community. At the time the project was given first priority, it was believed that sufficient funding could be obtained to support the ST and other astronomical projects that would provide a balanced NASA funded astronomy program. Under today's austere budget situation, he said that considerable concern was being expressed that funding requirements for the ST could divert funds from other projects deemed necessary for a balanced program. For this reason, the Space Science Board has appointed a study group to reevaluate priorities in space research. The study results are expected to be available in early 1976.

ANTICIPATED BENEFITS

It is impossible to predict exactly what may be viewed by the ST or to state emphatically that definite benefits will result from the project, but there is ample precedent from past astronomy programs to show that man has benefited.

Cost of the project has been of prime concern to the Congress as evidenced in FY 1975 when it directed NASA to reduce the project cost. Again in FY 1976 this concern was in evidence during the House Appropriation's Subcommittee on HUD-Independent Agencies hearings where a committee member expressed the opinion that the ST should not be a priority item because of its sizable cost and higher national priorities such as housing and urban problems. While the scientific benefits that could be derived from the ST were not in question, the point was made that the nation has an economic crisis and Congress is looking to make reductions where it can.

Past benefits from astronomy programs

Some of the past astronomy benefits include (1) predictions of seasonal changes, (2) development of techniques for navigation, (3) development of the theory of gravitation and the quantitative laws of mechanics which form the foundation for our technically advanced society, (4) identification of the theory of relativity which led to the development of nuclear fuel and power generation plants, and (5) understanding the possibility of using controlled thermonuclear fusion as a major energy source.

Future benefits with the ST

Using the ST, scientists are expected to be able to systematically study weather conditions on other planets which should lead to a better understanding of the Earth's weather and the origin of climate changes. Scientists know there are some violent explosions in the universe producing vast amounts of energy; and by studying the physical process of those explosions, new sources of energy may be discovered for use on Earth.

The ST also is expected to discover previously unknown phenomena which could contribute to man's basic needs. With the ST, scientists may be able to see the edge of the observable universe and even answer the age old question "Are we alone in the universe?"

It is extremely difficult to predict how soon definite benefits will start to accrue after the ST becomes operational. The NASA Administrator has stated that it could be within 5 years but that benefits from astronomy programs generally take longer.

CHAPTER 3

PROJECT STATUS

The ST project is currently in the definition phase of the acquisition cycle. Work in this phase includes detailed studies, comparative analysis, and preliminary design for the purpose of selecting a single project approach.

ESTIMATED COST

In July 1974 MSFC estimated that the 3.0-meter ST would cost about $463.8 million in real year dollars.[1] Included in this amount is $13.8 million for feasibility studies and definition work. The planning estimate included costs for design, development, production, launch, and one year of operations. Parametric estimating techniques were used for the planning estimate which was based on the assumption that the hardware development phase would start in fiscal year 1977 and that the ST would be launched in June 1982.

After reducing the size of the ST aperture from 3.0 to 2.4 meters, MSFC estimated in March 1975 that the project would cost $373 million in real year dollars which represents a $94 million net decrease in estimated cost. The net decrease resulted primarily from reducing the size of the ST aperture from 3.0 to 2.4 meters, refining the parametric cost model, changing escalation rates, and changing the projected launch date from June to December 1982. Except for these changes, the revised estimate provided for essentially the same work scope as previously planned for the 3.0-meter ST.

[1]Real year dollars means that projected inflation through project completion is included in the estimate.

OSS officials subsequently revised MSFC's planning estimate to a cost range of $378 million to $424 million; however, documentation was not available to show what specific adjustments were made. OSS officials advised us that they generally did not document revisions made to planning estimates. OSS officials also advised us that the planning estimates are stated as a cost range to reflect the degree of confidence in a particular estimate; to take into account other factors such as probable changes due to development contractor estimates, and additive factors such as the cost of contract administration.

Planning estimate

In July 1975 MSFC revised its March 1975 estimate and estimated the 2.4-meter ST would cost about $297 million in fiscal year 1977 dollars. The estimate was comprised of (1) $194.8 million for design and development of ST hardware, (2) $17.6 million for system engineering, integration, and program support, (3) $15.4 million for institutional management support[1], (4) $14.3 million for launch preparation and 1 month of flight operations, and (5) $55 million for contingencies.

The $297 million estimate represents a $76 million net decrease in MSFC's March 1975 estimate of $373 million for the 2.4-meter project. The net reduction resulted primarily from (1) a $63 million reduction in projected inflation resulting from stating the estimate in FY 1977 dollars rather than real year dollars, (2) a $2 million net reduction in operational costs, (3) a $7 million reduction in estimated contingency costs, (4) an $18 million reduction for cost to be borne by international participants, (5) a $14 million increase because of refinements to the initial estimate.

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[1] Institutional management support are those tasks performed by in-house and support contractor personnel that benefit the ST project.

OSS officials subsequently revised MSFC's $297 million estimate to a cost range of $370 million to $445 million in real year dollars. An MSFC official told us that the $297 million estimate was reduced to $260 million in fiscal year 1975 dollars and that about $110 million was added for contingencies and inflation to arrive at the $370 million low-range estimate. An additional $75 million was added for contingencies to arrive at the $445 million high-range estimate. At the completion of our review, this was the latest planning estimate for the ST project.

Cost not included in planning estimate

MSFC's July 1975 planning estimate of $297 million did not include costs for (1) tracking and data acquisition, (2) operations beyond the first month, (3) NASA personnel who work on the ST, and (4) Space Shuttle transportation.

MSFC currently estimates that $13.3 million in fiscal year 1975 dollars will be required to establish a tracking and data acquisition capability during the development phase. For the operational phase, MSFC estimates show an annual funding requirement of about $3.5 million in fiscal year 1975 dollars for tracking and data acquisition. Funding requirements for operating the ST will be studied during the remaining definition phase. Although no formal operating cost estimate has been prepared, MSFC's rough order of magnitude estimate shows an average annual cost of about $17.7 million in fiscal year 1975 dollars. The total annual post launch tracking and data acquisition and operations costs would equate to about 318 million fiscal year 1975 dollars throughout the expected 15 year life of the project.

An estimate was not readily available showing the costs for NASA personnel required for definition and development effort, but a portion of the definition work has been done by them. In addition, Space Shuttle transportation costs will not be known for several years; however, NASA currently estimates that each flight will cost $10.5 million in fiscal year 1971 dollars.

Need for a cost baseline

NASA does not consider any of the above discussed planning estimates adequate for use as a baseline for comparing planning estimates with current estimates and thereby determining whether the program is progressing as planned. In commenting on our report entitled "Need for Improving Reporting and Cost Estimating on Major Unmanned Satellite Projects" PSAD-75-90, dated July 25, 1975, NASA stated that development estimates, in lieu of planning or other preliminary estimates, should be used as initial baselines for progress measurement purposes.

We recognize that estimates prepared at or near the time development contracts are awarded are likely to be more accurate because better information is available. The ST development contracts, however, will not be awarded until about January 1977 which is several months after NASA plans to request congressional approval for the hardware development phase. For this reason, it is especially important that baseline cost data be established before the Congress is requested to approve the development work.

Furthermore, it is essential to have static baselines from which changes can be measured and referenced back to in order to accurately evaluate the progress of a major acquisition. Without such baselines, the Congress will not have full visibility over changes to estimates which served as a basis for major appropriation decisions.

SCHEDULE

In July 1974 MSFC's planning schedule showed a launch date of June 1982 for the 3.0-meter ST. MSFC's initial planning schedule for the 2.4-meter ST showed a launch date of December 1982 which represents a 6-month change in project launch dates. MSFC officials attributed the 6-month delay to the realignment of milestones to support NASA's current plans to request congressional approval for starting the development phase in fiscal year 1977.

MSFC's current schedule provides for completing definition work in March 1976, initiating the hardware development phase in January 1977, and launching the ST in April 1983. The April 1983 launch date represents a 4-month slippage in the initial launch date of December 1982 for the 2.4-meter ST. MSFC officials attributed the 4-month slippage to a reduction in early year funding requirements. They told us that NASA Headquarters imposed the early year funding limitation to hold down total spending for space science programs.

MSFC has not established baselines for intermediate schedule milestones because the project is still in the definition phase. Preliminary schedules, however, have been prepared to support the

April 1983 projected launch date. Some of the preliminary milestones include (1) selection of scientific instruments, (2) issuance of announcement of opportunity, (3) selection of science teams and participants at large, (4) release of request for proposals for hardware development, and (5) award of development contracts.

MSFC's planning schedule shows that the ST's four types of scientific instruments are to be identified between December 1975 and June 1976. After instrument identification, NASA plans to release an announcement of opportunity in June 1976 to the international scientific community for proposals to design and develop the scientific instruments, operate experiments, and document the scientific results obtained. The selection of instruments will take place after the scientific evaluation by a peer group of scientists and through consideration of the engineering, cost and compatibility with the ST. During the period between December 1976 and May 1977, science teams and participants will be selected from the proposals submitted.

MSFC plans to release requests for proposals in June 1976 for development of the major ST hardware elements and award the development contracts by January 1977.

PERFORMANCE GOALS

MSFC has not established performance baselines for ST development because the project is still in its definition phase; however, MSFC has established broad performance requirements which must be satisfied in order for the ST to meet its established objectives. The most significant change that has occurred in these broad performance requirements was the reduction of the telescope aperture size from 3.0 to 2.4 meters. The following chart shows some of the changes made in performance requirements.

Performance Requirement Changes

Requirement	Initial	Present
Telescope aperture (in meters)	3.0	2.4
Number of scientific instruments	7	4
Approximate weight (in pounds)	21,000	15,200
Electrical power (in watts)	2,500	1,500
Approximate visual magnitude[1]	28	27

MSFC officials told us that development of the 2.4-meter instrument would be less complex and that more "off-the-shelf" hardware could be used. They also said that the 2.4-meter instrument was well within the "state-of-the-art" whereas the larger instrument would have required certain technology advancements. Although its development may be less complex, a contractor evaluation shows that the 2.4-meter ST will be only 73 percent as effective as the 3.0-meter instrument primarily because of the reduction in light gathering capability.

OSS officials said "several other factors also affect the scientific efficiency of the ST, including the quality of the optics, the efficiency of the focal plane instruments and the detailed observing program. NASA estimates that the loss of scientific data from relatively bright objects will be insignificant. For very faint objects, only about half as many observations can be obtained but the amount of the science obtained will not be reduced by as large a factor."

MSFC officials said that the smaller light gathering capability would reduce the amount of scientific data obtained, but they said the 2.4-meter ST could still achieve its scientific objectives. Although

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[1] An astronomy term used for describing the brightness or faintness of celestial objects; for example, a star of the 27th magnitude would be approximately 2.5 times brighter than a star of the 28th magnitude.

the Space Science Board considered the 3.0-meter instrument to be the most desirable, it concluded that the smaller instrument would be a significant improvement over the best existing ground-based telescopes and most of the scientific data needed could be obtained by increasing the viewing time. NASA has determined that the viewing time will have to be about twice as long with the 2.4-meter ST. MSFC officials told us that increasing the viewing time does not have a significant cost impact.

Planning requirements

In June 1975 MSFC issued a revised performance requirements document containing broad performance goals for the 2.4-meter instrument. The overall performance goal established for the ST is to achieve near perfect optical performance over a wide spectral range with emphasis being placed on faint object observations.

As presently defined, the ST is to have the capability of operating for a period of 10 to 15 years. It will be about 41 feet long, 15 feet in diameter, and weigh about 15,200 pounds. Electric power for the spacecraft will be provided by solar arrays and batteries.

One of several critical performance goals being studied concerns the pointing and stability requirements of .007 arc seconds. This angle is comparable to steadily viewing a dime at a distance of 325 miles. It is not an absolute requirement but a goal and can be relaxed if necessary provided some other parameter or specification is changed to overcome the degradation from .007 arc seconds. NASA has achieved equal pointing accuracy with the Orbiting Astronomical Observatory for a shorter period of time than will be required for the ST. NASA does not regard this as a serious problem.

Another major requirement that is to be incorporated into the system design concerns the flexibility to replace scientific instruments when warranted by technological advances, changes in observational interest of the astronomical community, and performance degradations. This is a key design requirement because the ST is to serve as a permanent national astronomical space observatory.

Present design goals also aim for the ST to operate a minimum of one year without maintenance. The return of the ST to the ground by the Space Shuttle is the primary mode for major refurbishment, but NASA's technical requirements provide that the system design must have the capability for on-orbit servicing and maintenance. MSFC officials told us that based on preliminary reliability goals for the optical telescope assembly and the support systems module, there is about a 70 percent probability that the spacecraft will operate 100 percent effectively for the first year.

CHAPTER 4

TECHNICAL DEVELOPMENT UNCERTAINTIES

Many of the components and subsystems being considered for the ST have been developed for the Orbiting Astronomical Observatory, Apollo Telescope Mount, and other spacecraft developed during the past 15 years. Although NASA and its definition contractors have concluded that no major breakthroughs in technology are required, both recognize there are critical technology areas involved in development of the ST. Some of the areas NASA has identified during the definition work include (1) development of critical components (as defined below), (2) fine pointing and stabilization control, (3) control of contamination effects, (4) development of adequate thermal controls, and (5) testing limitations.

DEVELOPMENT OF CRITICAL COMPONENTS

There are some critical components and subsystems being defined for the ST. One of the most critical of the optical components is the primary mirror which collects light from the objects to be observed and forms their image . The mirror must be polished to very stringent tolerances. In addition, it must maintain its shape during the manufacturing process and in its operational environment.

MSFC officials believe that suitable materials are available for fabricating the mirror and that polishing machines of the required size and accuracy exist. NASA expects no major technical problems, since the necessary specifications have already been achieved with the 1.8 meter mirror.

However, a definition contractor advised MSFC that any deformation of mirror surface during polishing would result in image errors. The contractor also pointed out that correction of primary image errors after the mirror was fabricated would be a difficult and costly process.

Another critical technical area concerns the detectors required for the four scientific instruments. A detector functions much like a camera and takes the place of film in the space environment. Considerable concern has been expressed over the development of adequate detectors, and some reports have shown that detectors and their related technology is the most critical technical area involved in development of the scientific instruments.

One of the definition contractors, for example, advised MSFC that it was apparent that ST operational requirements and desired scientific data output exceeded the capabilities of existing detectors. The contractor also stated that development of improved detectors was a major technical and cost issue which required resolution. The ST Operations and Management Working Group also expressed concern over the development of adequate detectors. This group was established by NASA to provide overall scientific guidance to the project. They meet quarterly to evaluate problems related to project cost, schedule and technical requirements and recommend corrective actions when appropriate. This group concluded that detectors are a major technical problem in the development of scientific instruments.

MSFC officials agreed that detectors were a major area of technical concern because of their low reliability. They believe, however, that technology is available for development of detectors with the desired capabilities. In the event that adequate detectors cannot be developed in the required time frame, MSFC officials told us that detectors are available with less capabilities that could be used if necessary. They said, however, that use of these detectors would not provide the desired performance of the ST.

FINE POINTING AND STABILIZATION CONTROL

Pointing and stability requirements for the ST are more stringent than for any previous satellite developed, and they are considered to be one of the most critical technology areas in the project. NASA and its contractors have determined that uncertainties and design difficulties associated with gravity release, vibrations during launch, and thermal conditions may result in primary and secondary mirror misalignments between launch and on-orbit operations. Such changes could cause image blur and have a significant impact on fine pointing which will result in degradation or loss of all scientific data. NASA officials stated it would take a catastrophic change to result in loss of all scientific data and they believe this to be highly unlikely.

The pointing and stability requirements, therefore, are receiving special emphasis during the definition effort. MSFC and its definition contractors believe that the use of fine guidance sensors, sensor gyros, control moment gyros, reaction wheels, and electronic components will allow the ST to achieve the desired pointing stability. They also believe that the use of graphite epoxy, a relatively new material, for the metering truss will assist in achieving the stringent requirements. MSFC officials stated, however, that this requirement would need close attention throughout the development effort.

CONTROL OF CONTAMINATION EFFECTS

NASA and its definition contractors have determined that the ST will be very susceptible to contamination because of its physical size, expected long life, and sensitivity requirements. Evaluations of this problem during the feasibility and definition work have shown that contaminates such as dust, soil, lint, gases, and vapors could degrade optical and thermal system performance which would reduce the quality of scientific data obtained.

Because of the potential degradation that could result from contamination, MSFC officials told us that emphasis was being placed on evaluating the proposed contamination control system. As part of the current definition work, the contractors are preparing plans designed to control the problem of contamination. MSFC officials believe the measures being taken will satisfactorily resolve the potential contamination problem; however, they said that the effectiveness of the contamination control system and processing plans would not be fully known until the ST became operational.

DEVELOPMENT OF ADEQUATE THERMAL CONTROLS

The ST presents a unique challenge to the structural designer because of the extreme thermal and dynamic stability required in a very large, lightweight space structure. Some of the earliest studies of the ST system recognized that the temperature extremes of space orbit posed difficult thermal stability problems for the main telescope metering structure and the focal plane instrument support structure. In addition to the temperature extremes caused by the space environment, heat will be generated on board the spacecraft by the scientific instruments. These temperature variations, unless controlled, could result in ST performance degradations which would cause a reduction in the quality of scientific data obtained.

MSFC and its definition contractors are in the process of evaluating means to adequately control temperature fluctuations in which the ST must operate. As early as 1972, for example, MSFC suggested the possible use of a graphite epoxy composite for the telescope metering structure. This material has a much better stiffness than conventional material and its coefficient of expansion is much lower. MSFC officials told us that use of this material was expected to resolve the problem of misalignments between the primary and secondary mirrors caused by temperature changes.

In addition to the ST structures, MSFC and its contractors are evaluating means of dealing with the heat generated by the scientific instruments. One of the definition contractors has estimated that about 600 to 700 watts of heat must be rejected from the scientific instrument assembly in order to prevent instrument degradations. Although MSFC believes the thermal control system presently being defined will adequately reject this amount of heat, there is some uncertainty as to the amount of heat the scientific instruments will actually generate.

TESTING LIMITATIONS

In past spacecraft programs, a significant portion of program cost has been expended in assuring that the ultimate performance would be obtained in the initial flight unit because a means did not exist for recovering the unit for repairs or modifications. Assurance of performance therefore had to be obtained by extensive ground testing involving such costly items as facilities, large numbers of people, extensive development of test procedures, and considerable test analysis and evaluation. In addition, prior spacecraft test programs generally have provided for testing a system at each successive step in its assembly to ensure the attainment of full performance.

NASA and its contractors have determined, however, that a test of the total integrated ST system would be extremely difficult, costly and may not give the desired data. Because of the instrument's unique, high precision requirements and because of the effects of Earth environment such as vibration, atmosphere, and gravity, it may be impossible to test the telescope to its full image quality, and to even approach this goal would require very expensive test facilities.

NASA presently plans, therefore, to test and calibrate the ST at the highest practical assembly level. The total system, therefore, will not be ground tested to assure ultimate performance before being launched. Mathematical models and simulations will be used in lieu of much of the normal development testing. MSFC officials stated that they consider the performance risk associated with reduced testing to be acceptable.

Under this test concept, the ST would be thoroughly checked out after launch under space environment conditions which can never be perfectly simulated on the ground. From an analysis of both engineering and scientific data, a determination will be made as to whether the ST requires modifications. If so, these would be accomplished by a Space Shuttle visit.

CHAPTER 5

PROGRESS MEASUREMENT

Because of the complexity and cost of modern spacecraft systems, it is essential that total program visibility be maintained during all phases of the acquisition cycle. To obtain such visibility, a technique must be used which provides current, accurate information showing where the time-phased progress of an acquisition actually stands in relation to where it was expected to stand at a given point in time in terms of cost, schedule, and technical performance.

Without such information, an accurate determination cannot be made on whether an acquisition is being accomplished at a cost higher or lower than was planned, proceeding in accordance with established schedules, or meeting its technical performance requirements. Conversely, when integrated cost, schedule, and technical performance data are reported regularly on a summarized basis and compared to firm, time-phased goals for these elements, early warning signs of impending cost overruns, schedule slippages, and performance degradations should be detected in sufficient time for management to initiate appropriate action.

An effective progress measurement system should contain the following three elements:

- --a uniform method for defining, collecting, reporting, and correlating management data.
- --a method for establishing firm, time-phased goals for each major element of the acquisition.

--a technique for the continuous comparison of actual work accomplished with that planned.

Because of the extensive amount of data generated in the development and production of major spacecraft systems, a uniform approach must be used for collecting, reporting, and reviewing the data. Use of work breakdown structures provides a consistent framework for defining and assigning work, establishing and maintaining a data base, and controlling and reporting progress.

If progress is to be measured with any degree of accuracy, it is also important that realistic cost, schedule, and technical performance goals be developed for the system and agreed to by the Government and contractor activities involved. In addition, controls must be designed and established to prevent undisciplined changes. It is also important that the established goals be divided and assigned to each element of the work breakdown structure.

The continuous analysis of work actually accomplished versus that planned can provide early warning signs of impending problems in time for corrective actions. Major problems causing unfavorable variances may already be known to management, but a performance measurement system documents the cost impacts on a systematic, routine basis. It will also assist in identifying and tracing smaller variances to their source before a major cost impact results.

PRESENT PROGRESS MEASUREMENT SYSTEM

NASA's current management procedures do not require the implementation of a formal progress measurement system until the project's development phase. However, MSFC's current management information system does provide timely data to NASA management echelons showing the current status of the definition work being accomplished.

The major techniques used to monitor the ST definition work are prescribed in a project definition plan dated July 1973. The plan, in essence, requires a series of periodic management reviews and status reports covering various aspects of cost, schedule, and technical performance.

Management reviews

Periodic management reviews are scheduled throughout the life of the project according to its unique needs and requirements. The reviews are designed to keep NASA management at the program and project levels informed of current cost, schedule, and technical status. The reviews also include presentations on existing or potential problems being encountered during the definition work.

The definition contractors are required to hold four major status reviews during the project definition phase. These reviews are scheduled to coincide with major schedule milestones of concept selection, design selection, completion of program planning requirements, and final contract review. Each review is to provide current status data covering system and subsystem analysis, design, and program definition. During the final contract review, the contractors will be required to (1) summarize all definition work accomplished, (2) present final study results and recommendations, and (3) highlight key design features, issues, and cost estimates.

MSFC maintains surveillance over the definition effort through frequent telephone contacts and visits to contractors plants and other NASA installations. Each of the subsystem managers provide input to the MSFC project manager who prepares weekly notes to higher MSFC management echelons. These notes highlight significant activities related to the project, including any problems being encountered.

As lead NASA center, MSFC is responsible for keeping NASA Headquarters appraised of current cost, schedule, and technical status of the project. This is accomplished primarily through detailed programmatic and technical status presentations which cover all aspects of the project, including future plans and potential problems. Major reviews are also required when (1) approval to proceed to the next phase of the acquisition cycle is required, (2) significant progress has been made, or (3) key milestones have been reached.

Status reports

In addition to the frequent management reviews, reports on cost, schedule, and technical performance are used to keep NASA management informed on the status of the definition effort. These reports are prepared by all project participants, including the definition contractors, MSFC, other NASA centers, and NASA Headquarters.

MSFC study contractors submit monthly progress reports which provide a means for assessing contractor performance. The reports provide visibility of progress made and highlight significant accomplishments during the month. Although the reports document major actions on a monthly basis, MSFC officials told us that contractors' performance is monitored on a more frequent basis through telephone contacts and plant visits.

MSFC prepares and submits to NASA Headquarters semiannually a program operating plan showing project funding requirements and planning schedules. The program operating plan includes input from the other NASA activities participating in the project.

As noted earlier, NASA also established an ST Operations and Management Working Group to provide overall scientific guidance to the project. Minutes of the working groups quarterly meetings are distributed to appropriate NASA management personnel and members of the scientific community.

FUTURE PROGRESS MEASUREMENT SYSTEM

As a part of the definition effort, the contractors are studying a progress measurement system for implementation during the hardware development phase. MSFC officials said that the system would include all levels of management: subcontractors, prime contractors, MSFC, other NASA centers, and NASA Headquarters. They also said that the contractor system would be required to conform to requirements stated in MSFC regulations and that the contractors would be required to submit reports which would permit NASA to maintain total visibility over the development effort.

MSFC's current regulations require contractors to implement a system for tracking internal resources, schedules, and technical performance to assist in managing the contracted effort. The contractor's system is required to provide a correlation of cost, schedule, and technical performance data into a total performance measurement system based on an approved work breakdown structure. The work breakdown structure is to depict all effort required to accomplish the contract statement of work, and it is to be product oriented and represent work to be performed. In addition, the work breakdown structure is to include all major prime and related subcontracts.

The contractor also is to establish budgets for all authorized work through each organizational level to the lowest level of contract planning. Authorized work is to be scheduled in a manner which describes the sequence of work and identifies the interdependencies required to meet the requirements of the contract.

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